

# 4 TRANSPORT AND THE URBAN ENVIRONMENT

Road transport contributes significantly to urban air pollution in many countries. The World Health Organization estimates that suspended particulate matter leads to the premature death of over 0.5 million people per year. The economic costs of air pollution have been estimated to be equivalent to about 2 percent of gross domestic product in many countries. Incorporation of environmental issues within an urban transport strategy requires the identification of the main transport-generated pollutants (usually suspended particulate matter, lead, and ozone) and the mobilization of technical, fiscal, and system management controls on fuel and vehicle technology to reduce these pollutants. Frequently these will also contribute to a desirable reduction of greenhouse gas emissions.

## THE SCALE OF THE ISSUE

For many poor people in developing countries, the inability to access jobs, education, and health facilities is viewed as the most serious constraint on their quality of life (Narayan 2000a). Motorized transport is often crucial to poor people, but because they frequently live and work in the shadow of motorized transport, they are also the most vulnerable to its adverse environmental impacts. Environmental protection must therefore be seen as an essential part of the task of improving the quality of life of the poor, and not as a luxury to be purchased at the expense of the poor's mobility.

A comprehensive strategy for transport and the urban environment should cover the built environment, including land take, urban form, visual intrusion of infrastructure and traffic, and cultural heritage; the social effects of transport in causing occupational or locational resettlement and community severance; personal safety and security; and the more commonly recognized prob-

lems of noise and air pollution (local, regional, and global). All of these concerns must be formally addressed in a typical project's environmental assessment.

In this review we deal with matters concerning the built environment in chapters 2 and 6, with the social effects in chapter 3, and with safety and security in chapter 5. In this chapter we deal only with various forms of pollution, especially air pollution.

In developing countries an estimated 0.5 million to 1 million people die prematurely each year as a result of respiratory and other illnesses caused by exposure to urban air pollution. This is a larger number than those dying as a consequence of urban traffic accidents, although because of the age distribution of those afflicted, traffic accidents probably reduce life-years more. Exposure to lead contributes to behavioral problems and learning disabilities in urban children. It also reduces the quality of life.

## GLOBAL WARMING

It is now generally agreed that a global climate change is occurring. It also appears that the poorer countries stand to suffer most as a consequence of this change, with estimated costs in the range of 5 to 9 percent of gross domestic product (GDP) for some of the poorer countries—several times greater than the relative effect in industrialized countries.<sup>1</sup> It is estimated that the transport sector is responsible for about 25 percent of emissions of the gases contributing to global warming in industrialized countries, but only about one-half this amount in developing-country cities.<sup>2</sup> While the proportion appears to have been stabilized in the Organisation for Economic Co-operation and Development (OECD) countries, it is still growing in the developing countries as motorized transport increases. This increase in motorized transport is concentrated in urban areas. Although controversy continues over the optimal greenhouse gas (GHG) reduction strategy, and the distribution of action between industrialized and developing countries, it is accepted that some mitigating strategy is called for in all countries.

Despite this, GHG mitigation has a negative connotation in many developing countries, where exhortations to limit GHG emissions are perceived as a denial of the right to develop the services and lifestyle being enjoyed by industrialized countries. The apparent unwillingness of some industrialized-country governments to take strong action also does not help, while the inherent long-term and nonlocal nature of the negative impacts of GHGs feeds this attitude.

A “business-as-usual” scenario for the transport sector offers little prospect of relief. The principal components determining the level of GHG emissions in transport are the level of activity (in ton or passenger kilometers), the modes of transport used, the energy intensity of each mode, and the mix of fuels used. In the industrialized countries, transport activity has increased *pari passu* with economic growth, the shift to the pri-

vate car and air transport has worsened the modal balance effect, and changes in the balance of fuels has had little impact. It is only the dramatic increase in fuel efficiency that has acted as a brake on GHG emissions. Even so, transport GHG emissions continue to grow in the industrialized countries even though overall emissions have been stabilized. Economic growth in the developing countries similarly threatens to dominate any attenuating effect of technology improvement.

To avert this outcome requires a combination of transportation policy reforms in the short term and technological changes in the longer term. The question is how to get such policies adopted. The suggested key to changing this situation is to link GHG-mitigation policy initiatives to goals that are perceived to be of immediate relevance (such as local air pollution and balance-of-payments considerations) and to try to uncouple, or at least “flex,” the link between economic growth and GHG emissions from the transport sector.<sup>3</sup>

We start from the observed synergy between GHG reduction and local environmental and economic interests. The GHGs that most contribute to global warming in the transport sector include carbon dioxide (CO<sub>2</sub>), methane, and nitrous oxide (N<sub>2</sub>O). Emissions of CO<sub>2</sub> are directly proportional to the quantity of carboniferous fuel consumed; other things being equal, reduced fuel consumption will reduce economic costs and global pollution simultaneously. Better traffic flow conditions typically reduce fuel consumption per kilometer. In chapter 6 we advocate both road-based traffic management and traffic restraint measures to that end, while the measures that are suggested to improve public transport in chapter 7 and to improve nonmotorized transport (NMT) in chapter 8 should have similar effects. More generally, local air quality improvement programs for urban transport in middle-income countries such as Mexico and Chile have also shown some collateral benefits for reducing GHG emissions.<sup>4</sup> While the rest of this chapter focuses primarily on local air pollution reduction, much of it also

relates, by implication, to the global warming issue. Because these types of interventions can be shown to be in the immediate self-interest of city residents themselves, it is believed that concentrating on exploiting the synergy between GHG reductions and local economic and environmental interests is likely to be the most productive strategic stance.

This must be supported by economic incentives. Fossil fuel consumption is influenced directly by fuel choice, vehicle size, and fuel efficiency, and indirectly by individual and corporate decisions on activity location and style, and transport mode. Emissions of methane come largely from leakages of gasoline, diesel, and unburned natural gas and are thus susceptible to influence by fueling infrastructure improvement. The strongest incentive to fuel economy in actions in all these dimensions is the monetary cost of fuel. It has been shown that pollution controls supported by appropriate prices or taxes are much more effective than is the use of regulations alone.<sup>5</sup> In chapter 10 we discuss this in detail, arguing for fuel prices that at least cover the full social costs of fuel consumption.

Unfortunately there is not always a synergy between local air pollution and GHG emission-mitigation measures. The current generation of diesel vehicles appears to be more damaging to public health than are gasoline or gas-powered vehicles. Thus, while diesel is a particularly efficient fuel from the point of view of reducing GHG emissions, only the new generation of clean diesels should have a role in GHG strategy. Furthermore, mitigation measures for local pollution focus on emissions of vehicles in use, whereas the entire life cycle (from well to tailpipe) is relevant for analysis of GHG emissions. Worldwide policies to reformulate transport fuels to mitigate local pollution by means of severe hydrotreating (particularly recent moves in North America and the European Union [EU] to limit sulfur in gasoline and diesel to 10–50 parts per million by weight [wt ppm] or lower) make refinery processes increasingly energy intensive, increasing GHG emissions. N<sub>2</sub>O can

increase significantly when catalysts used to convert nitric oxide (NO) or nitrogen dioxide (NO<sub>2</sub>) begin to be deactivated.

A strategic response is therefore required to address situations where the synergy is weak or negative and where a tradeoff between local and global effects appears. In this context, the Global Environment Fund (GEF), a multidonor fund administered by the World Bank, has promoted the concept of the “global overlay.” This is a procedure in which measures developed to target other objectives are subject to a scrutiny exploring the possibility and cost of modifying them to yield GHG reductions. In this way an attempt is made to identify and concentrate on those areas where GHG reductions have the least “opportunity cost.” Through GEF’s Operational Program 11, on transport, GEF funding is available both for the development of new globally friendly technologies and, on an incremental cost basis, for other interventions that pilot promising current GHG reduction policies. An early grant under this scheme is supporting the development of infrastructure for bicycle movement in an outer area of Manila. The Bank has also established a “Prototype Carbon Fund” to foster the international transfer of certified emission reductions under the Clean Development Mechanism, as defined in Article 12 of the Kyoto Protocol.

Technological measures to secure GHG reduction perform primarily through the replacement of the vehicle stock. This may take up to 20 years to complete for cars and up to 30 years for freight vehicles. In developing countries, however, most of the change of vehicle stock is through growth, so that strategies affecting new vehicles may have a more rapid effect on emissions per unit of activity. Hence, with GDP rising, the best way to achieve a decline in GHG emissions by transport vehicles is a combination of policy reforms in the short term and technological changes in the longer term. Because most vehicle users are driven by economic motives, this implies a need for strong support from taxation and pricing instruments. “Closing the loop,” so that revenues

from increased taxation or charges for vehicles or fuels are seen to contribute to improvement in the transport sector, is likely to be a necessary condition to secure acceptance of the policies at the political level. This is further discussed in chapter 10.

## NOISE AND OTHER DISTURBANCES

*Noise* from transport appears to be considered much less seriously in developing countries than in high-income countries. While there have been studies of the physical damage resulting from exposure to occupational noise, these have been mostly in manufacturing establishments. The levels experienced in developing-country streets, while not pleasant, approach but do not exceed the lower limits above which noise is considered an occupational hazard. Attitude surveys do not show urban transport noise to be perceived as a serious hazard.

Other disturbances exist. Heavy road traffic volumes can make roads dangerous and difficult to cross, causing *community severance*. It is reported that in Jakarta, businesspersons routinely take taxis just to get safely to the other side of the busiest thoroughfares. Barriers, footbridges, and tunnels may reduce the danger but increase the severance, particularly in countries where these facilities appear to be constructed and located to improve motor vehicle flow rather than to assist pedestrians (see chapter 5).

Severance can in some circumstances be reduced by the grade separation of motorized traffic and mass transport from pedestrian movements. In established cities, tunneling is often too expensive (and technically difficult for major flows of road traffic for ventilation reasons) so that elevation is the only viable possibility. This can cause significant *visual intrusion* as well as restrict the dispersion of fumes from traffic remaining at ground level. The elevated rail transport system so dominates Silom and Sukhumvit roads in

Bangkok that the government has decided to avoid any further elevated mass transit in the central area. The problems of community severance and visual intrusion can, to some extent, be reduced by good engineering design. The main lesson from experience is that community severance and visual intrusion have often developed because of inadequate coordination among strategic planning, transport infrastructure investment planning and design, and management of private participation in infrastructure. That emphasizes some institutional requirements, to which we will return in chapter 11.

## URBAN AIR POLLUTION

By far the greatest environmental concern about urban transport in most cities relates to local air pollution. Designing an appropriate strategy, with limited resources, to address this concern requires careful identification of priorities, both in selecting targets and in selecting instruments.<sup>6</sup> This section first identifies the major local air pollutants produced by urban transport, and assesses the significance of their contribution to the total urban environmental burden. On this basis, we then discuss four main types of instrument for consideration as components of a strategy for reducing the impact of transport on the urban environment. The first two types—actions on transport vehicles and transport fuels—are primarily technological. The other two types of instrument—traffic management and fiscal instruments—while requiring technological support for effective implementation, are “softer” policy instruments. In some countries, such as Mexico, public transport improvements are sought primarily for environmental reasons.

### MAJOR TRANSPORT-GENERATED AIR POLLUTANTS AND THEIR SIGNIFICANCE

Vehicular emissions are very damaging to health.

- a. High *lead* concentration in the bloodstream may increase incidence of miscarriages in

women, impair renal function, and increase blood pressure. Most significantly, it retards the intellectual development of children and adversely affects their behavior. More lead is absorbed when dietary calcium intake is low, in cases of iron deficiency, when the stomach is empty, and by the young, so poor malnourished children are particularly susceptible to lead poisoning. Suspended particulate matter, particularly particles from vehicle emissions and tire wear that fall predominantly in the submicron range, are able to penetrate deep into the respiratory tract, cause respiratory problems, exacerbate asthma, and damage lung function. There is also a growing consensus that diesel exhaust poses a serious cancer risk.<sup>7</sup>

- b. **Carbon monoxide (CO)** inhibits the capacity of blood to carry oxygen to organs and tissues. People with chronic heart disease may experience chest pains when CO levels are high; at very high levels, CO impairs vision, manual dexterity, and learning ability, and can cause death.
- c. **Sulfur oxides (SO<sub>x</sub>)** which are emitted in direct proportion to the amount of sulfur present in fuel, cause changes in lung function in asthmatics and exacerbate respiratory symptoms in sensitive individuals; they contribute to acid rain and to the formation of secondary particulate matter.
- d. **Oxides of nitrogen (NO<sub>x</sub>)** cause changes in lung function in asthmatics, contribute to acid rain and secondary particulate formation, and are a precursor of ground-level ozone. Both diesel- and gasoline-fueled vehicles contribute to NO<sub>x</sub> emissions.
- e. **Ozone** is responsible for photochemical smog and decreases pulmonary function in individuals taking light to heavy exercise. NO<sub>x</sub> (which is emitted in significant quantities by gasoline- and diesel-fueled vehicles) and photochemically reactive volatile organic

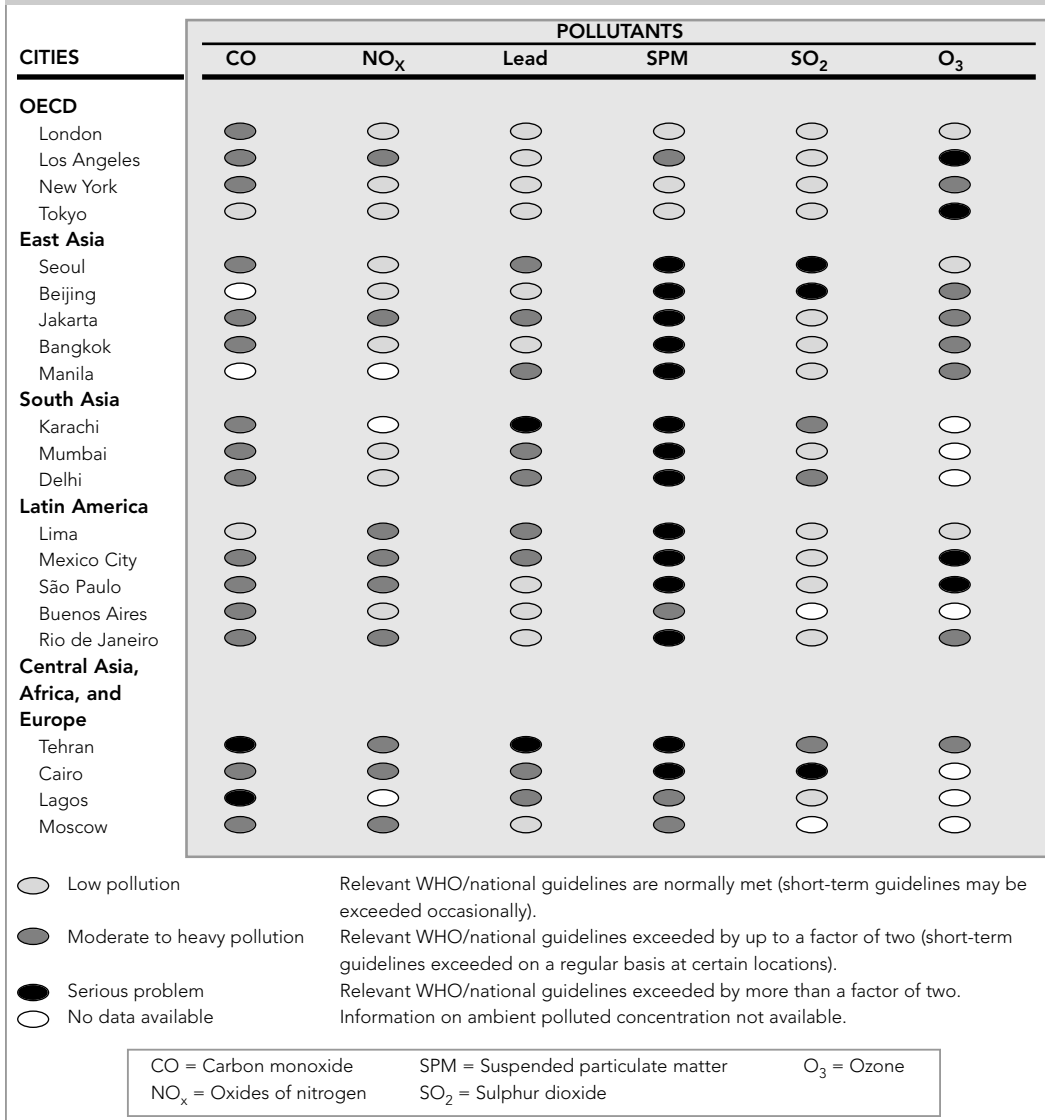
compounds (to which emissions by gasoline-fueled vehicles contribute) are the two main precursors of ozone.

While all of these emissions are potentially damaging, their incidence and their health impacts differ substantially, both between pollutants and between regions. World Health Organization (WHO) studies of megacities, although now somewhat dated, show that, although health norms of all major pollutants are widely exceeded, the significance of the problem varies considerably (WHO 1992). Lead excesses over norm are very serious where leaded gasoline is used, but not usually elsewhere. Excess of CO is typically not nearly as great as that of fine particulate matter, particularly in countries where the consumption of gasoline is relatively low compared with that of diesel. Significantly elevated levels of ambient SO<sub>2</sub> tend to come from the combustion of coal much more than from the transport sector. Ambient NO<sub>2</sub> concentrations are often below the WHO guidelines, but are on the increase, as are those of ozone (figure 4.1).

When risk assessment of susceptibility to physical excesses are combined with evidence of health impacts from dose and response analysis, studies in a number of cities (for example, Bangkok; Cairo; Mexico City; Quito, Ecuador; and Santiago) have indicated that the greatest damage to human health comes from exposure to fine particulate matter (particles smaller than 2.5 microns in aerodynamic diameter, or PM<sub>2.5</sub>) and to lead. Depending on topographical and meteorological conditions, ozone can also be a serious health problem in large metropolitan regions, as it is in Mexico City and Santiago.<sup>8</sup>

Transport is not the only source of urban air pollution. In particular, industrial and domestic use of fossil fuels—especially heavy fuel oil, biomass, and brown coal—is a significant source of ambient particulate matter and sulfur dioxide (SO<sub>2</sub>), especially in temperate regions such as China and Eastern Europe.

**FIGURE 4.1 OVERVIEW OF AMBIENT AIR QUALITY IN SELECTED CITIES: SUBJECTIVE ASSESSMENT OF MONITORING DATA, VARIOUS YEARS IN THE 1990s**



Source: The data for figure 4.1 have been assembled by Asif Faiz and Surhid Gautam, World Bank, from various sources. These include: World Bank project reports; Urban Air Quality Management Strategy reports, World Resources Institute; a study of seven cities undertaken for the Latin America and the Caribbean Clean Air Initiative; Indian Central Pollution Board reports; and unpublished data obtained by direct inquiry from various cities (São Paulo, Santiago, Bangkok).

Any strategy to reduce pollution from the transport sector needs to be seen in this broader context.<sup>9</sup> However, urban transport is generally identified as a high-priority action area for several reasons.

- Urban traffic is a large contributor to the most harmful fine particulate emissions, and it is responsible for up to 80 to 90 percent of atmospheric lead in cities where leaded gasoline is still used, for the greatest part of

- CO emissions, and for significant contribution to the formation of ground-level ozone.
- Large stationary sources of air pollution, which are often located at a distance from densely populated city centers, disperse into the higher layers of the atmosphere while vehicles emit near ground level in highly populated areas. Consequently, vehicles contribute more to human exposure than their share in total emissions loads would indicate. In a study of six megacities, vehicles accounted for only 6 percent of emissions in tons emitted but 32 percent of average exposure for the population.
  - The urban transport sector is one of very rapid growth and change, which makes it very susceptible to positive and to protective actions. An understanding of the environmental significance of alternative transport policies and actions may enable growing cities to avoid the environmental impacts already endured in the megacities.

#### **FUEL POLICY**

Fuel policy measures may affect the polluting characteristics of existing fuels, the selection among available fuels, and the total amount of fuel consumed.

#### **Improving fuel quality**

For the World Bank's client countries, the first step in improving the quality of transport fuels is to phase out lead in gasoline. Lead has historically been added to gasoline as an octane enhancer. Because of its toxicity, there is now a worldwide move to ban its use in gasoline. More than three-quarters of the gasoline sold worldwide today is unleaded. Virtually all OECD countries and many large developing and transition countries, including Bangladesh, Brazil, Honduras, Hungary, Malaysia, and Thailand, have already eliminated lead in gasoline.<sup>10</sup> Some very large countries, including Indonesia, Venezuela, and most countries in Sub-Saharan Africa, remain to be converted.

In the absence of other significant sources of lead, eliminating lead additive in gasoline can reduce

ambient concentrations of lead to less than 0.2 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) and the level of lead in blood to lower than 5 micrograms per deciliter ( $\mu\text{g}/\text{dl}$ ), below the 10  $\mu\text{g}/\text{dl}$  level now considered by many health organizations to be the appropriate norm. The necessary strategy should attend both to the introduction of unleaded fuel and the elimination of leaded fuel.

Eliminating lead additive from gasoline can also trigger wider environmental improvement. The availability of unleaded gasoline throughout a country is a prerequisite for the introduction of catalytic converters to reduce the emissions of  $\text{NO}_x$ , CO, and hydrocarbons. The level of CO emissions can also be reduced by incorporating oxygenates into gasoline. It is important, however, to stress that lead elimination should not be carried out in isolation because many of the gasoline-blending components used to increase octane after elimination of lead have their own adverse health effects. Excessive presence of benzene and total aromatics in unleaded gasoline would be of particular concern. However, controlling gasoline volatility and adjusting refinery operations and processing units can manage these blending components at a reasonable cost during the lead phase-out process.

Sulfur in diesel and gasoline generates emissions of  $\text{SO}_2$ , causes acid rain, and contributes to particulate emissions. It can be reduced by hydrotreating the base fuels. However, in countries where the carbon component of vehicular particulate matter remains high, it may not make economic sense to attempt to match North American and EU sulfur standards immediately in order to mitigate particulate emissions from diesel engines.<sup>11</sup> Rather, tightening of standards should be carefully phased in the light of country-specific circumstances. In some extreme cases, proposed emissions standards are incompatible with the transport fuels available on the market. For example, insistence on Euro 2-compliant buses when the sulfur level in the diesel available in the country may be as high as 5,000 wt ppm is not technically coherent. Some regional effort

may also be necessary to harmonize refining and import standards to avoid local black markets in high-sulfur diesel. Transport, environment, and energy policies must always be carefully aligned.

It is not enough to regulate fuel quality. In many developing countries, old, poorly maintained vehicles dominate vehicle fleets. This reduces the cost effectiveness of imposing stringent fuel specifications.<sup>12</sup> Moreover, in some countries transport fuels are routinely adulterated. For example, the addition of (lower-cost) kerosene to gasoline in Asia (box 4.1), cross-contamination of diesel with crude oil, and addition of lead additives to gasoline downstream of refineries or terminals in Central Asia and the Caucasus all increase vehicle emissions. Regular fuel-quality monitoring, together with costly penalties for noncompliance, could help enforce fuel standards more effectively, although preventing local adulteration is likely to remain very difficult as long as there is any financial incentive to engage in the practice.

Fuel-quality requirements are location specific, depending on climatic conditions, ambient concentrations, vehicle fleet characteristics, and so on. For example, Chile and Mexico have more stringent standards than do other Latin American countries because of the particular pollution char-

acteristics of their capital cities. Countries that have domestic refineries merit special attention in this context because refinery processes are integrated, and changing the specifications of one fuel can affect the quality of other fuels and overall refinery economics. While many countries have fuel standards, most of these standards are stipulated in the form of fuel composition. In the United States, the combination of allowing the option of fuel certification on the basis of vehicle emissions, in lieu of fuel composition, and regional differentiation of specifications has allowed the refining sector the freedom to seek flexible least-cost solutions for meeting specific vehicle emissions standards.

The governments own many refineries in developing countries. Some are not operated economically at present. Revamping refineries to improve fuel mix and quality is likely to render them even less commercially viable. Under these circumstances the government may resist requiring changes in fuel quality, or will embrace them only while maintaining import protection through restrictions or high tariffs. In some developing countries, the net cost to society of improving fuel quality by importing superior fuels would be lower than the costs resulting from the use of domestically manufactured fuels with less-stringent spec-

#### **BOX 4.1 FUEL ADULTERATION IN THAILAND**

Adulteration of heavily taxed gasoline by highly subsidized kerosene was a serious problem in Thailand in the early 1980s. The government introduced a number of measures, including:

- Dyeing the kerosene blue
- Requiring kerosene to be sold in 20-liter containers only
- Extensive enforcement efforts by the police.

Although these measures had some effect, sales of kerosene remained high until oil taxes were restructured in 1986 and the tax on kerosene increased between 1986 and 1991 to remove the incentive to adulterate. However, the incentive to adulterate gasoline with untaxed industrial solvents remains, and such adulteration is a continuing problem.

Source: Jitendra Shah, private correspondence.

ifications. Downstream petroleum-sector reform through transfer of ownership from the government to the private sector, coupled with liberalization of petroleum product trade and the introduction of competition, can therefore result in improved fuel and, ultimately, urban air quality.

### **Substituting cleaner fuels**

A range of alternative fuels considered to be cleaner than conventional hydrocarbons continue to be under investigation or development in industrialized countries. For substitutes to be attractive in the developing world, they must be seen not only as addressing locally perceived environmental problems but also as economically viable at the individual and national levels. It is in that context that the potential of new fuels for urban transport in the developing world must be appraised.

*Compressed natural gas (CNG)* is a relatively clean fuel.<sup>13</sup> Natural gas is available in abundance in many developing countries that do not have other indigenous fuel resources—such as Argentina, Bangladesh, and Thailand—and hence is potentially of great balance-of-payments significance. As transport use of CNG alone is not enough to justify the development of gas fields and the construction of gas transport and distribution infrastructure, the availability of CNG for transport is closely linked to its availability through city gas distribution networks. These exist in many large cities in Bangladesh, Brazil, Colombia, Indonesia, Pakistan, Eastern Europe, and the former Soviet Union. Some governments have already specifically mandated the use of natural gas as the transport fuel in highly polluted areas (for example, for taxis in Buenos Aires and, more recently, for buses and all pre-1990 auto-rickshaws and taxis in New Delhi, India).

The environmental benefit of CNG is not undisputed. Although recent tests by the New York City Transit Authority have shown that natural gas buses have better local pollutant emission characteristics than do ordinary diesel buses, their emission advantages are significantly lowered or

even eliminated when compared with diesel-powered buses running on ultra low sulfur diesel and equipped with a continuously regenerating particulate trap. Similarly, although the overall global warming impact of cars fueled by CNG is lower than that with gasoline (especially where the natural gas would otherwise be flared), gasoline vehicles that are converted to natural gas suffer from potentially high leakage of the GHG methane. Although some good retrofitted kits (for example, those used in Argentina) work efficiently, many do not. For example, the conversion of a fleet of Mercedes buses in Rio de Janeiro is reported to have increased most emissions except those of particulates.

A second disadvantage concerns the economic and technical sustainability of the technology in developing countries. The New York City Transit Authority reported that CNG vehicles pay a 30 to 35 percent energy premium over diesel vehicles. Technically, of a fleet of 40 CNG buses in Jakarta, 20 were out of operation in mid-2001 due to maintenance problems. Dual-fuel vehicles also carry some extra cost penalties and reliability problems. Again in Jakarta, a fleet of Nissan dual-fuel vehicles is now being run as single-fuel (diesel) vehicles for technical reasons.

The economics of CNG are complex. Because the choice of fuel generally rests with the business or individual, the critical factor is ultimately the cost and convenience of CNG compared with that of other fuels. As far as the fuel is concerned, the Intergovernmental Panel on Climate Change (IPCC) estimated the wellhead gasoline equivalent production cost of CNG to lie between 70 and 90 percent that of gasoline or diesel, so that given differences in distribution and storage costs, the cost at the pump (excluding taxes) could be very similar. The actual real resource cost thus depends critically on the local availability of fuel and density of the distribution network.<sup>14</sup> As far as vehicles are concerned, there is extra cost associated with the CNG engine (or its conversion), the fuel control system, and the fuel tanks. Together these increase the cost of a

basic vehicle, whether a bus or a car, by up to 30 percent.<sup>15</sup> The convenience factor is also important because CNG vehicles lose significant amounts of luggage and passenger space to fuel tanks; at low penetration levels, refueling can involve some dead-running and can be time-consuming; vehicle range may be reduced by over 50 percent, doubling the refueling frequency. Considering all these factors, international evidence suggests that, except for some very heavy mileage vehicles, the pump price difference would need to be about 50 percent of the production cost of liquid fuels for natural gas to be attractive to users. Hence natural gas would seem to require strong fiscal encouragement if it is to be more than a niche fuel.

**Liquefied petroleum gas (LPG)** is a mixture of light hydrocarbons, mainly propane and butanes. It is easier to distribute and store than CNG,<sup>16</sup> and although the octane number of LPG is not as high as that of natural gas, it has excellent anti-knock characteristics allowing dedicated propane vehicles to take advantage of engines with slightly higher compression ratios than can be used with gasoline. The limited amount of highly reactive hydrocarbons and the low sulfur content of LPG in comparison with gasoline or diesel are some of LPG's good environmental features; it does, however, contain olefins, which are photochemically reactive. LPG-powered three-wheelers are commercially available in Bangkok, and have already effectively replaced the old two-stroke gasoline-powered "tuk-tuks."

The main problems in introducing LPG to the transport sector are the supply sources and distribution system. Several countries already import significant amounts of LPG. India, Pakistan, and Sri Lanka, for example, import about 30 to 40 percent of their LPG demand. On the distribution side, LPG is stored under pressure both inside the vehicle and in the refueling tanks. Special refueling equipment is needed to transfer the pressurized liquid from storage tanks to the vehicle and to ensure that no LPG escapes during refueling. As with CNG, the required investments

in LPG distribution and refueling stations have not been made in most developing countries, and the need for such stations remains a constraint on widespread LPG use.

**Ethanol and methanol.** True biofuels (that is, those without substantial fossil fuel use hidden in harvesting and processing) would give a real reduction in GHG emissions, but these are still elusive at costs competitive with those of gasoline or diesel. The only long-term effort to promote biofuels for transport in developing countries, the sugar-ethanol program of Brazil, appeared attractive as a means of saving foreign exchange when oil prices were at their peak, but has lost most of its attractiveness; the new car market in Brazil is now almost exclusively for gasoline vehicles. In any case, many experts argue that only alcohol produced from cellulose can truly claim a GHG benefit.

**Electric vehicles.** Electric road vehicles are quiet and nonpolluting at their point of use and have obvious attractions as urban vehicles, whether powered directly, as in the case of electric trains or trolleybuses, or indirectly, as in the case of some buses, small vans, and cars. A program for electric three-wheelers is being undertaken in Kathmandu, Nepal (box 4.2). While these have the lowest environmental impacts at point of use, their overall environmental impact depends on the way in which electricity is generated and stored, and the disposal problems associated with expired batteries, which can be substantial. Whatever that environmental balance, the market attractiveness of electric-powered transport depends, as is the case for other fuels, on its economic attractiveness in terms of overall cost and convenience. At present the economics of electric vehicles are far from favorable.<sup>17</sup>

Battery technology is central to the economic success of battery electric vehicles. Lead-acid batteries, currently used in electric vehicles, take 6 to 10 hours to slow-charge, emit hydrogen when recharging (requiring indoor recharging facilities to be well ventilated) and still have very limited range. Other battery types are still in the development

#### BOX 4.2 ELECTRIC THREE-WHEELERS IN KATHMANDU

In 1993, faced with growing air pollution in Kathmandu, the government of Nepal banned the sale of new diesel three-wheelers imported from India. In the same year, the Kathmandu municipality invited the United States–based Global Resources Institute to design an electric three-wheeler for the city. The pilot vehicle, known as “safa tempo,” was put on the road in September 1993, and U.S. Agency for International Development (USAID) support expanded to buy eight vehicles, promote the program, and train mechanics. When USAID funding ended in 1996, two local business groups started assembling, servicing, and operating electric vehicles, which sell for about \$6,000. In September 1999 the government finally banned all existing diesel three-wheelers. There are now six suppliers of electric vehicles, and as of May 2000, the city has over 500 battery-powered three-wheelers, each capable of carrying up to 12 passengers. This is the world’s largest fleet of electric passenger transport vehicles for use on public roads. The future is not secure, however. In May 2000 the government approved the import of 300 15-seat vans with the same preferential import duties accorded to the electric vehicles. In May 2001 it decided to ban new or transferred registration of all three-wheelers, including safa tempos, although that decision was later rescinded under pressure from donors.

Source: *The Wall Street Journal Europe*, May 30, 2000.

stage, and significant efforts are being directed to electric–internal combustion engine hybrids rather than pure electric engine vehicles. The economics of electric vehicles also depends on the price of electricity. The power sector in many developing countries is currently undergoing reform and restructuring. The long-term viability of electric vehicles should be evaluated from the standpoint of market-based power pricing. Given the current state of technology, electric vehicles would not be expected to have widespread applications; with carefully considered government intervention, however, they could play a useful, though limited, role in extremely polluted traffic corridors. Moreover, the greenhouse characteristics of electric vehicles depend critically on a full fuel cycle analysis; if the electricity is produced from present mixes (coal, oil, or gas), there may be no greenhouse benefit at all compared with a small internal combustion engine.

*Hybrid diesel-electric* vehicles are now being developed with some success and tested in industrialized countries under a GEF grant. Their cost is similar to that of a heavy CNG vehicle. Onboard diesel engines operated at constant

load to maintain battery power for peak demands and in sensitive areas can give a 30 percent energy savings compared with a conventional diesel vehicle.

**Hydrogen fuel cell.** This is a widely advocated “sunrise” technology, at least for heavy-duty urban vehicles. Fuel-cell buses are already being used in trial projects, including a program funded by the United Nations Development Programme. The environmental performance of these vehicles—depending on the source of the hydrogen—can far exceed that of CNG or improved diesel engines, and their life-cycle operating costs are projected to be lower than that of CNG or diesel. It is possible that we will see such vehicles deployed in active service in urban fleets (buses and urban freight delivery applications) in the industrialized countries in about a decade. It is unlikely, however, that they will have early application in the developing countries.

#### **Influencing fuel consumption**

In industrialized countries technological improvements in engine efficiency tended to decrease both local and global pollution in the 1970s and

the first half of the 1980s, although effective reductions in fuel consumption have subsequently been lost in the United States by increases in vehicle size. Possibilities for further improvement in new-vehicle fuel economy arise from reduction of vehicle size or weight; direct fuel injection, lean-burn technology; measures to increase the share of diesel (which may, however, adversely affect local pollution); and optimized engine transmission systems and hybrid vehicles. Fuel-consumption standards, such as the corporate average fuel efficiency (CAFE) standards imposed by the U.S. government and those more recently agreed on between Association des Constructeurs Européens d'Automobiles (ACEA—the organization of the European motor industry) and the European Commission, have attempted to force the pace of technological progress in this respect.<sup>18</sup>

In developing countries, fuel economy is affected by what is occurring in the industrialized countries through the availability and cost of imported second-hand vehicles, but they also have special problems of their own. Fuel economy is often low because of poor vehicle maintenance, fuel adulteration, and a number of other factors. Using gasoline with an octane number that is lower than that recommended by vehicle manufacturers—either because lower-octane gasoline (for example, 80 research octane number [RON]) is available and is less expensive or because gasoline is adulterated with kerosene—can decrease fuel economy, lead to knocking and ultimately to engine damage, and to higher emissions. Hence a rather different focus may be appropriate for policy on fuel economy in developing countries.

The scope for improving fuel economy is greatest in countries where a large fraction of vehicles have low engine compression ratios. In the new independent states of the former Soviet Union, many vehicles run on gasoline with a motor octane number as low as 72. Increasing the octane and the engine compression ratio will result in fuel savings—and reductions in GHG emissions—in the long run.

### **A staged strategy for fuels**

The timing of the development of fuel-cell technology may have a significant part to play in strategic thinking about the alternatives. CNG requires significant investment in gas production, distribution infrastructure, and vehicles, which would only be recouped over a substantial period. The incremental cost of cleaning up the performance of diesel is significantly lower. Except in a few cities where the CNG infrastructure is already in place, it may make more sense, as an interim strategy, to concentrate on getting the diesel vehicles currently on the road performing well and cleanly, to gradually reduce sulfur content in diesel fuel, and to bring in cleaner diesel-vehicle technology in new vehicles on the road, while waiting for the cost of fuel cells to become viable.<sup>19</sup>

### **VEHICLE POLICY**

Environmental issues for vehicles can be divided into those relating to improving new-vehicle technology, those relating to replacing the existing stock by more environmentally friendly technology, particularly with respect to motorcycles, and those relating to the use of the existing vehicle stock. Although we discuss vehicles and fuels separately here, in practice they must be considered simultaneously.

#### **Improving vehicle technology**

Largely in response to stricter vehicle emissions requirements, considerable progress has already been made in developing vehicle hardware to reduce emissions. Efficiently operated three-way catalytic converters can reduce exhaust CO and hydrocarbon emissions of gasoline vehicles by as much as 95 percent and NO<sub>x</sub> by over 75 percent. Similarly, state-of-the-art diesel vehicles that use ultra low sulfur diesel fuel and continuously regenerating traps can be almost as clean as vehicles that use CNG. Such advanced technologies are unlikely to offer cost-effective solutions in very low income countries in the near future, but their existence makes the point—an important one to keep in mind in formulating incentive policies—that not all diesel vehicles are alike.

The EU, Japan, and the United States lead the world in setting stringent vehicle emissions standards and fuel specifications. These countries are pursuing the best available technology for further reducing emissions from new vehicles. The control measures include a combination of the following: dramatic reduction of sulfur in gasoline and diesel, to extend the useful life of the catalyst and to enable new catalyst technologies for reducing  $\text{NO}_x$ <sup>20</sup> and particulate emissions; new measures for control of tailpipe emissions (for example, particulate traps with regeneration for diesel engines); emerging vehicle technologies such as common-rail direct-injection diesel engines; and the use of alternative fuels for very low emission or zero emission vehicles (as are mandated in California). Although the rest of the world will probably adopt these standards and technologies some day, the issue for developing countries is how to phase in these measures cost-effectively.

In encouraging the use of catalytic converters in developing countries, a number of conditions need to be satisfied to ensure that they function effectively. These conditions are (a) wide availability of unleaded gasoline and, preferably, complete phase-out of leaded gasoline, to eliminate the chances of misfueling; (b) differentiated taxation during the transition period to prevent misfueling;<sup>21</sup> (c) a reasonably low level of sulfur in gasoline, preferably lower than 500 wt ppm; (d) specification of the emissions performance levels and the length of time during which the catalyst system must meet those levels; and (e) effective inspection and maintenance (I/M) to ensure that converters are operating properly. If these conditions cannot be fully satisfied, the additional cost associated with the installation of converters may not be justified by the benefits.<sup>22</sup> Even where effective use of catalytic converters is considered feasible, governments should consider specifying emissions levels for new vehicles rather than mandating catalytic converters per se. Retrofitting in-use vehicles with catalytic converters is not usually considered cost effective.

### Options for motorcycles

Motorcycles account for about one-half of the vehicle fleet in many Asian cities (and up to 75 percent in some). In many cities motorcycles offer substantially greater speed and flexibility of movement than do inadequate and congestion-bound bus services, while being broadly comparable to them in cost. In Taiwan, China, the ownership is already 0.55 per capita. The majority of motorized two- and three-wheelers in Asia are powered by two-stroke engines, which are preferred because they have a (now only slightly) lower capital cost than do four-stroke engines, have more power (higher power-to-weight ratio, higher specific output, higher torque, and low revolutions per minute response) for a given displacement, and are simpler to self-maintain.

Unfortunately, conventional two-stroke engines are environmentally very damaging because of their inherent combustion technology; their poor maintenance and misfiring, particularly at cold start; and their frequent and excessive use of lubricants not manufactured for use in two-stroke-engine vehicles.<sup>23</sup> In Delhi, India, for example, 45 percent of particulate emissions and two-thirds of unburned hydrocarbon emissions in the transport sector are estimated to come from two- and three-wheelers powered by two-stroke engines. Despite this, no country has issued standards for PM (particulate matter) emissions for two- and three-wheelers, largely because there is no proven methodology for measuring oil droplets (although smoke standards might be used as a proxy standard for two-stroke engines).

The balance of advantage between two-stroke and four-stroke technologies is changing. The difference in capital cost is rapidly being eroded.<sup>24</sup> Taking into account differences in fuel economy and the lower cost of crankcase oil than two-stroke oil, the total annual operating cost of owning and operating a four-stroke can already be lower than that of owning and operating a two-stroke. Furthermore, the decision of one of the major market economies, Taiwan, China, to impose stringent environmental standards on

two-stroke motorcycles starting in 2004 is likely to shift the economies of scale in production in favor of the four-stroke, and to concentrate future technical development on the four-stroke technology. Already, Japanese manufacturers appear to be concentrating their sales efforts on four-strokes, even where two-strokes are still legal.

Basic two-stroke technology can be improved at source by emissions-reduction technologies including electronic control for fuel metering and improved scavenging characteristics, or by after-treatment.<sup>25</sup> Two-stroke engines manufactured in India, meeting year 2000 emissions standards, emit very little PM. Unfortunately, the durability of catalyst and secondary air systems is limited because of the high concentration of hydrocarbons in the exhaust gas.<sup>26</sup> Retrofitting of improved technology is relatively expensive and ineffective for this category of small vehicle. It is therefore advisable that governments specify emissions levels for new vehicles and adopt policies to secure premature replacement for high polluters, rather than mandate catalytic converters per se. The key is to switch to four-stroke engines.

New technology does not deal with the problem of the high average age and low replacement rate of vehicles currently in use. For these vehicles, emissions on the road are usually much higher than are emissions levels found during tests, due to bad operational and maintenance practice. They are estimated to emit more than 10 times the amount of fine particulate matter per vehicle kilometer than is a modern car, and only a little less than a light diesel truck.<sup>27</sup> In some countries, such as Bangladesh, low-octane gasoline is used (80 RON, compared with a recommended minimum of 87 RON), and gasoline is often adulterated with inexpensive kerosene, causing engine malfunction. It is also common for the proportion of lubricant in the fuel mix to be two to three times the recommended level, even though this both increases cost and reduces performance. Nevertheless, given the strong current preference for the use of two-stroke engines, mandatory

scrappage of existing fleets is likely to be politically difficult. Phasing out more gradually might be achieved by the imposition of differential license fees, according to technology and location, to encourage more-polluting vehicles to move into rural areas where pollutant concentration is less. The same effect might be achieved by refusing to license high emitters in the cities or limiting the maximum permissible age of vehicles. Subsidy of environmentally advantageous scrap-and-replace programs might also help. For two-stroke vehicles remaining in use, the first step might be to mandate an appropriate lubricant standard. Maintaining the recommended mixtures (2 percent oil for two-wheelers and 3 percent for three-wheelers) might be facilitated by the sale of premixed fuel. Driver education is an important source of improvement in this respect (box 4.3). Improved I/M are also powerful instruments.<sup>28</sup>

The evidence thus suggests a number of strands in a strategy for addressing the motorcycle problem.

- The information basis for policy needs to be improved through more systematic measurement of ambient air quality, the introduction of PM standards for new two-strokes, public information campaigns on fuel mix and vehicle maintenance, identification of locally cost-efficient retrofit technologies, and the establishment of secure common institutional commitment (police, inspection agencies, and so on).
- Standards on new motorcycles should be regularly reviewed and progressively tightened in the light of technological possibilities. This process would be enhanced if government announced long-term objectives with respect to fuel quality and vehicle emissions standards.
- Existing two-stroke performance should be improved by introducing minimum gasoline octane requirements (87 RON), mandating appropriate oil standards, introducing premixed fuel, introducing systematic I/M, and offering incentives for conversion to clean fuels for three-wheelers.

#### BOX 4.3 THE BENEFITS OF INFORMATION: LUBRICATING TWO-STROKES

It is a commonly believed fallacy in some countries that if a little oil is a good thing, more must be better. In Dhaka, Bangladesh, many operators of two-stroke three-wheelers use less-expensive straight mineral oil rather than the recommended two-stroke oil. Because this gives less lubrication, they also tend to use as much as 8 or even 12 percent mix compared with the recommended 3 percent for two-stroke oil. Since two-stroke oil cost twice that of mineral oil in June 2000, following the recommended procedures would actually give a savings of 25 to 40 percent in oil costs as well as reduce engine damage and emissions. But bad habits are inbred in a generation of operators and mechanics. To counter such misinformation, training sessions for mechanics and “auto clinics” for three-wheeler taxi drivers were therefore held in 2000 under the Energy Sector Management Assistance Program. Similarly, in Pakistan, pamphlets containing basic information on fuel and lubricants have been distributed by the Hydrocarbon Development Institute.

Source: Masami Kojima, World Bank.

- High polluters should be eliminated through a program including the statistical identification of high-polluting ages and categories, testing followed by improvement to standard or buy-in of nonconforming vehicles, the introduction of tax- or license fee-incentives for low polluters in cities, and the reduction of import duties on environmentally benign vehicles and parts.

#### Using the existing stock of vehicles

The share of emissions is not uniformly distributed over the vehicle fleet. A fraction of all vehicles—ill maintained, often old—is typically responsible for a disproportionately high amount of pollution from the transport sector. If these “high emitters” (typically, commercial vehicles and public transport vehicles, including, in some places, two- and three-wheeler taxis with two-stroke engines) can be repaired or eliminated permanently, a considerable reduction in pollution can be achieved at relatively small cost.

The implementation of such a scheme is far from simple. To be cost effective, any scheme targeting high emitters should identify polluting vehicles with high annual vehicle kilometers traveled operating in densely populated areas. Old vehicles in very poor condition may be candidates

for retirement. Those that are highly polluting but are better maintained may be considered for repair or for retrofitting with more recent vehicle technology. Complicating the issue is the fact that in some cities, such as Cairo, the proportion of old, gross polluters may be very high, with the result that targeting does not leave very many vehicles out of the scope.

#### APPLYING ENVIRONMENTAL STANDARDS

To apply environmental standards, it will be necessary to design appropriate vehicle inspection and maintenance programs, scrappage programs, as well as ensure that related policies are appropriate, and provide the correct incentives, including those related to domestic taxation, trade liberalization, and public expenditures.

#### Inspection and maintenance programs

Vehicle emissions standards and technologies are not effective without proper maintenance. Poorly maintained vehicles are high emitters and are responsible for a disproportionate share of total vehicle emissions. Data collected in India in November to December 1999 during a series of I/M “clinics” for two-wheelers indicated that minor vehicle repairs improved fuel economy by an average of 17 percent and reduced CO emis-

sions by 44 percent. A well-run, uncorrupt I/M program should be able to strengthen the enforcement of emissions standards significantly.

Introducing effective I/M programs has proved difficult. For example, recent experience in Wuhan, China, showed that in roadside testing, 93 percent of vehicles fell short of the standard even though 97 percent of those tested in the same period at the I/M station met it.<sup>29</sup> Thus, wider use of spot-checking equipment capable of identifying major problems from any relevant vehicle type, and of fixed I/M stations for more thorough examination and follow-up of vehicles so identified, holds promise of significant impact on the pollution problem. An appropriate system of fines, and controls thereof, could also make

such system self-financing. As far as off-road testing is concerned, experience from various parts of the world suggests that an I/M system based on centralized, high-volume, inspection-only centers with computerized emissions measurement to minimize tampering and corruption, such as the I/M system in Mexico City, is likely to be more effective than is a decentralized system with a large number of private garages participating in the I/M. If the proper controls are in place, the private sector can be an important partner in operating effective I/M programs (box 4.4).

The usual reason for not properly maintaining vehicles is to avoid out-of-pocket expenses. There are, however, certain maintenance practices that would actually yield cost savings. An example is

#### **BOX 4.4 PRIVATE SECTOR VEHICLE INSPECTION AND MAINTENANCE IN MEXICO CITY**

Mandatory testing for vehicle emissions in Mexico City was introduced in 1988. Initially testing was done in government test-only centers as well as in private garages that were permitted to both test and repair. Although the private sector in Mexico undertook testing more economically, initially as many as 50 percent of vehicles were estimated to obtain passes falsely. A more limited number of private test centers were therefore subsequently licensed for testing only. The Mexican experience shows that an effective testing system must evaluate emissions levels accurately, and issue and enforce certificates without corruption. To achieve this it is necessary that:

- The legal framework provides sanctions to be applied for failure to carry out the testing protocols correctly
- The testing stations must be subject to monitoring by independent bodies, and sanctions must be properly applied
- Repair work should be separate from testing
- The pass certificate must be easy to monitor
- There should be sufficient monitors (for example, traffic police) to ensure a low probability of evasion by vehicle owners
- The fine for not displaying a legal emissions test certificate should be sufficient to discourage evasion
- The technology of testing should exclude the possibility of temporary “tuning” to pass the test
- The number of licensed centers should not be too large, to avoid garages being “soft” to increase market share
- All testing centers should be subject to rigorous implementation of protocols and inspection of their procedures.

Source: World Bank 2001.

use of the correct kind and amount of lubricant in the two-stroke engines that are common in South Asia (box 4.3 above). At a minimum, wide public education campaigns should be undertaken to promote cost-effective practices.

### **Scrappage programs**

When emissions standards are enforced effectively, the cost of owning old vehicles actually increases, making vehicle renewal more attractive.<sup>30</sup> Vehicle retirement and scrappage programs can further encourage this phenomenon as long as it is possible to identify gross emitters that are operating at a high annual rate of vehicle kilometers and that still have reasonable remaining economic lives. Considerable care is needed in designing such schemes, however. Using age as a proxy for high emissions does not always identify the worst cases. If the program is directed at urban pollution, it must also prevent the import of old vehicles from outside the city to take advantage of the retirement bonus. Evidence in Europe that may be relevant for some of the higher-income developing countries suggests that—because gross emitters are typically owned by low-income households that are often in no position to purchase much newer vehicles—cash-for-scrappage schemes may be more effective than cash-for-replacement schemes.<sup>31</sup> In the most polluted areas, it may even be possible to use cash-for-scrappage schemes to influence modal split.<sup>31</sup>

In many developing countries, particularly those in which particulate emissions are the most serious pollution concern, commercial vehicles (buses, trucks, and taxis) are the greatest contributors to urban air pollution. Some countries have been quite successful in stimulating early replacement of these vehicles. For example, Hungary offered large cash incentives for replacement of old buses and trucks with new vehicles complying with most recent emissions standards (\$3,600 in 1997 dollars for a bus replacement). In the early 1990s Chile combined tax incentives with preferential treatment of environmentally benign vehicles in competitively tendered fran-

chising arrangements to remove the most-polluting diesel buses from the urban transport fleet.

### **Domestic taxation policies**

The importance of taxing fuels at a level that reflects the externalities, as well as the border costs and any proxy charges for road maintenance costs, was emphasized in a recent World Bank sector policy paper.<sup>33</sup> Although the cost of mitigating impacts is logically a better foundation for defining appropriate levels of environmental taxation valuation of damage, the evidence on marginal damage costs of the six megacities, quoted above, suggests taxes around 60 percent of the import cost of gasoline and 200 percent of that of diesel fuel.

These estimates emphasize not only the importance of the absolute levels of fuel taxes and prices but also their relative levels. Around the world the retail price of diesel is typically lower than that of gasoline, because of differential taxation. The trend is particularly pronounced in South Asia. In Bangladesh, for example, the retail price of gasoline was almost double the price of diesel in 1999. The price differential, together with the low profit margin fixed by the government for the sale of gasoline, has led to the adulteration of gasoline with kerosene and, as an unintended consequence, higher particulate emissions from vehicles. In Pakistan, where the price difference is even higher, the diesel-gasoline ratio consumed in the transport reached 5.3 to 1 in fiscal 1999/2000, which is very high by international standards. Relative tax rates may thus be encouraging the highest-mileage urban vehicles (taxis, mini-buses, and so on) to switch from gasoline—not to CNG or other clean fuels but to diesel, the fuel with the most damaging urban environmental impacts. A large price differential between kerosene and gasoline, based on the use of kerosene by the poor as a domestic heating fuel, leads to illegal addition of kerosene to gasoline, resulting in higher pollutant emissions.

The usual reason for low tax rates on diesel is its use for heavy interurban freight movement and

agricultural purposes. Given that the health impact of particulate emissions is likely to be lower in low-density interurban and rural areas than in cities, the emphasis on the economic rather than the environmental impact of diesel fueling outside urban areas may not be unreasonable. Hence it is necessary to develop tax structures that protect the urban environment but that do not discourage use of the most economical fuel by agriculture or intercity freight vehicles. One possible way of doing that is to identify the most damaging vehicle types (cars, urban mini-buses, and vans) and use high duties on those types of diesel vehicle, rather than fuel taxation, as the means of changing the balance of economic advantage. That is already being done in some countries by exempting clean vehicles from import duties or vehicle license duties. Another option is to increase the tax on diesel to make the price of automotive diesel comparable to that of gasoline, but to rebate industrial and agricultural users of diesel. This approach has been adopted successfully in Chile. Another is to tax automotive diesel more and use a dye to distinguish automotive diesel from diesel for other uses.

Setting *relative* tax levels is a complex issue. In principle, one should identify the emissions values of different pollutants and structure vehicle and fuel taxes to reflect differences in the summed value of emissions for different vehicle types. In practice, however, emissions levels depend not only on the fuel type and composition but also on where and how it is burned. Moreover, the evidence on the health costs of different pollutants remains sketchy. At best, then, the use of fiscal incentives would be somewhat rough and ready. Nevertheless, on the basis of successful application of fiscal incentives in industrialized countries, it is possible to confidently recommend differentiation of excise taxes between leaded and unleaded gasoline, and between diesel and CNG.

Tax structures that discourage the purchase of new vehicles—for example, registration fees or excise taxes based on the market value of the

vehicle—may have adverse environmental impacts that should be weighed against their perceived distribution effects. Possible measures include replacing import tariffs on new vehicles by ownership taxes reflecting the environmental quality of the vehicle, eliminating the system under which vehicle registration fees are proportional to the book value of the vehicle (which makes it more expensive to own new vehicles than old ones), and minimizing the tax on the purchase of new vehicles. The fiscal impact of these changes might need to be offset by an increase in direct charges for road use. In some middle-income countries, it may be necessary to consider a safety net to offset the immediate impact of making it more costly for the poor to operate old vehicles, particularly in the taxi trade.

#### **Trade liberalization**

It is common for developing countries to use tariffs or trade barriers to protect domestic industry and to prevent the expenditure of scarce foreign exchange on luxury goods that are not essential to economic growth. Where either of these arguments is applied to the import of vehicles, the effect is likely to be the protection of outdated technology. Liberalization of vehicle trade is hence an important step, particularly in countries that have automobile-manufacturing facilities. The removal of barriers that hinder access to the technology available in the rest of the world would enable consumers in these countries to meet tighter emissions standards at least cost. Rules such as local content requirements (for example, requiring that 70 percent of the vehicle weight or content must be produced domestically) often result in inefficiency and in heavier vehicles if the percentage is based on weight. High import tariffs on new vehicles, rigid licensing schemes for imports, and quotas are all likely to slow the rate of vehicle renewal, with potentially adverse impacts on air quality (pollution); their distributional impact must therefore be weighed against their environmental effects.

Free trade in used cars raises the question of “environmental dumping.” Among the largest

recipient markets for used cars are Cyprus, Jamaica, Peru, Sri Lanka, and the Russian Federation, while Japan remains the largest identifiable single source of used-car exports. The forces driving the export of used cars by industrialized countries will become stronger as emissions standards become more stringent and regulations concerning the end-of-life vehicle are implemented, as in the EU.

In the interest of environmental protection, the government may limit the age of the vehicles that may be imported. For example, Hungary set the age limit to 10 years old in 1991 and progressively reduced it to 8, 6, and finally in 1997, 4 years old. Chile bans imports of used vehicles altogether. However, the purchasing pattern of vehicle owners should be carefully balanced against the hypothetical environmental advantage of restricting the import of old vehicles. If commercial operators (and, in some of the transition economies, low-income households) are in no position to buy relatively new vehicles, such an import restriction constrains the supply, and increases the price of replacement vehicles, postponing the replacement of high emitters. However, a combination of higher general taxation on motoring and environmental standards on vehicles is always likely to reconcile restraint on car use with environmental protection better than discriminatory import taxation.

Transport fuel is also an internationally traded commodity. Having an open border and being able to take advantage of superior fuels manufactured in other countries makes it much easier to phase lead out of gasoline and to implement other fuel-quality improvement measures. In some parts of the world, there is a move toward harmonizing fuel specifications to ensure minimal environmental standards, foster intraregional trade, and enhance the efficiency of supply. Fuel specifications in North America, the EU, and the countries of the former Soviet Union are already harmonized, for the most part. Similar measures have been proposed in Latin America.<sup>34</sup>

### **Public expenditure policies**

The traditional role of public sector expenditure in addressing environmental externalities centers on the provision of classic public goods. These public goods include (a) maintenance of an emissions inventory and (b) setting and enforcement of standards, including establishing I/M arrangements (even if these arrangements are implemented by the private sector).

Environmental benefits are often attributed to public transport subsidies because of modal transfers from car to bus, or from bus to rail. Generally, these arguments should be treated cautiously for two reasons. First, the "preferred" modes only yield benefits if they are well patronized. Poorly loaded buses are more environmentally damaging than are well-loaded cars. Second, the environmental benefit only accrues if the subsidized modes draw their patronage from an environmentally inferior mode, rather than from new trip generation. In the case of car–public transport transfers, the evidence is that the cross-elasticity of demand between car driving and public transport is low. In the case of rail-bus transfers, which are the most common, the problems concern the financial and economic cost of securing the transfers. It is therefore wise to draw a cautious conclusion: not that it is impossible to secure environmental benefit from public transport subsidies, but that subsidy alone might be an inefficient means of securing that environmental benefit. Public transport subsidy is best addressed in the much wider context of improving congestion and distribution, as well as in the context of environmental benefits. Other forms of environmentally focused subsidy can represent better value for money. As argued above, well-targeted support of premature retirement of environmentally damaging vehicles or fuel conversions is much more likely to yield high benefits-per-dollar committed.

There is, of course, much more to public expenditure decisions. Giving priority to infrastructure for public transport and NMT may be more effective in changing modal choice than may subsidies,

and may also be more consistent with the general poverty reduction strategy of poorer countries.

### **SYSTEM MANAGEMENT POLICIES**

System management policies to reduce the environmental impact of urban traffic can be divided into three categories. These categories are (a) those giving priority to less-polluting modes, (b) those relieving the impact by allowing traffic to perform in a more environmentally friendly way, and (c) those relieving the impact by reducing traffic volumes.

#### **Public transport priorities**

In developing countries, buses are often the transport mode of choice for the poor, but they are frequently highly polluting because of the many stops and starts and idle running of engines in heavy traffic. Giving priority to buses not only reduces their direct environmental impact but also improves their attractiveness with respect to the private car. It also improves their finances. The construction of separated busways, as has been done in several Brazilian cities, or even a highly integrated priority bus network, as in Curitiba, appears capable of affecting car ownership and, more significantly, car use. It is still doubtful how far good bus services by themselves can defer or deter motorization. The case for bus priorities will thus be a combination of economic, distributional, and environmental considerations.

In this context it is appropriate to consider the concern that economic liberalization of transport operations will have adverse environmental consequences. In road haulage, where liberalization is best established, it has usually increased both average vehicle size and load factor. As long as this is accompanied by adequate enforcement of emissions standards, the effect should be beneficial rather than harmful. In the bus industry the opposite appears to have happened, with both average vehicle size and load per vehicle falling, often in the context of poor environmental enforcement. In the absence of a well-functioning regulatory system, complete liberalization of

bus services, such as has occurred in Mexico City and Lima, has clearly increased environmental pollution. That outcome is not inevitable, however. For example, faced with this effect in Santiago, the Chilean government successfully introduced competition “for the market,” in the form of a competitively tendered franchising system using environmental quality of the vehicle as one of the selection criteria. This highlights the importance of concentrating on regulatory reform, rather than simple deregulation; this is discussed further in chapter 7.

#### **Traffic management**

Traffic congestion reduces average speed and increases most emissions (except for NO<sub>x</sub>). Traffic congestion worsens the emissions of both local and global pollutants. Increasing the average speed in city traffic from 10 kilometers per hour (km/h) to 20 km/h could cut CO<sub>2</sub> emissions by nearly 40 percent. Increasing vehicle speed from 12 to 15 km/h to 30 km/h in Bangkok and Kuala Lumpur was estimated to be equivalent to installing three-way catalytic converters in 50 percent of the cars in these cities. Experience suggests, however, that though it is possible to reduce congestion in the short run, this favorable result invites greater car use in the long run, thus ultimately resulting in further congestion. Studies have shown that measures to decrease traffic congestion by providing more road space eventually increase the volume of traffic.<sup>35</sup>

More subtle forms of traffic management may be able to reduce unit emissions rates without generating extra traffic to negate the benefit. Coordination of traffic lights is generally beneficial. Traffic-calming devices, which slow traffic down but do not stop it, may also result in cleaner, as well as safer, traffic. Good signage can prevent excessive “hunting” movements for scarce parking space.

#### **Traffic restraint**

In the industrial economies, demand for more space in lower-density settlement, and the vehi-

cle ownership and use associated with it, have all proved income elastic, while at high incomes and low motoring costs, the price elasticity of demand for car travel has been low. Increased vehicle fleet and mileage may therefore appear inevitable as economies develop. The political feasibility of denying those economic characteristics has also been widely doubted.

In some of the world's most congested and polluted cities, politicians are reassessing that conservative judgment; some quite direct attacks on vehicle use have been recently made for environmental reasons. Exclusion of some vehicles, selected by registration numbers from all roads on particular days, as in the "hoy no circula" ("do not drive today") scheme, first imposed in Mexico City in 1989 and subsequently copied in other cities, such as São Paulo, can result in dramatic reductions in traffic volume during the first months of implementation. In the longer term, however, the schemes may be counterproductive because some households purchase an additional vehicle or retain an old and polluting vehicle that would have otherwise been replaced, in order to avoid the effect of the restrictions. The most recent variant of this strategy, the "pico y placa" ("peak-hour restrictions by license plate number") scheme in Bogotá, applies only to peak hours, but increases to two the number of days per week on which each vehicle is kept off the road.

Further focusing restraint to exclude all vehicles from particularly sensitive areas (such as pedestrian-only city shopping centers or residential areas) is now adopted in many countries, and is increasingly being provided for in initial planning of new development. When first introduced it was believed that this type of measure would reduce trade in the controlled areas and hence be resisted by traders. In actuality, however, it appears not to have had that effect and, when associated with good planning of preferential public transport access, can reduce private road traffic over a broader area.

For the broadest impacts, economic instruments still look the most promising. The World Bank energy sector strategy argues that it should be the objective for all countries to integrate local environmental and social externality costs into energy pricing and investment decisions.<sup>36</sup> The extreme case is that of Singapore, where very strong political action to limit the stock of cars to that deemed sustainable has been implemented through the auctioning of a controlled stock of certificates to purchase vehicles as well as by congestion pricing in the CBD and some of its major freeway accesses.<sup>37</sup> The existence of a single jurisdiction with the ability to use the revenues from vehicle taxation to finance other supporting elements of a comprehensive policy seems important to that case. Perhaps equally significant, in the United Kingdom the legal provision of revenues from congestion pricing to accrue to the local authority introducing it has been the basis for the development of new enthusiasm for the pricing device from business as well as environmental interests.

In some industrialized countries, studies also indicate that, in the long run, own-price elasticity for gasoline consumption is significant enough to make fuel taxation a potential policy instrument for reducing vehicle usage and kilometers traveled. A World Bank study concluded that a judicious use of gasoline tax could save the citizens of Mexico City \$110 million a year more than would an otherwise well-designed control program with no gasoline tax.<sup>38</sup> This might be accentuated by converting some of the other costs of ownership (such as insurance, parking, and vehicle taxation) into costs of use, although in many developing countries these charges are low and often evaded.

NMT modes are the least polluting of all modes, as well as often being the less expensive for short-distance movements. The elimination of impediments to NMT thus has environmental benefits, in addition to the poverty focus advantages discussed in chapter 8.

## CONCLUSIONS: A STRATEGY FOR URBAN TRANSPORT AND ENVIRONMENT

A number of strong conclusions arise from the above discussion of strategic priorities.

### *On basic knowledge*

Better basic understanding both improves policy identification and helps to persuade decision-makers to implement the policies:

- Local data collection and analysis on vehicle registrations and on levels and sources of ambient air pollution
- Development of better understanding of the health impacts of different small particulate emissions from transport (although this development may be better left to the industrialized countries)
- Dissemination of basic knowledge on environmental impacts of transport modes (for example, optimal oil/fuel mix for two-stroke gasoline engines)
- Education campaigns on efficient vehicle operation, maintenance, and so on.

### *On technological priorities*

While it is generally preferable to concentrate on performance standards, rather than on specific technology preference, there are some relatively clear-cut technological priorities:

- Elimination of lead from gasoline
- Replacement of two-stroke by four-stroke motorcycles
- Elimination or cleaning up of high-mileage, heavily polluting vehicles; the Bank can help both with technical assistance in these fields and, in some cases, with the financing of public infrastructure and incentive mechanisms to stimulate change
- Introduction of computerized I/M regimes administered by centralized, private sector contractors, subject to scrutiny to prevent corruption, and targeted initially at old and high-polluting vehicle categories.

### *On managing transport demand*

Technological and fiscal measures must be complemented by a coherent transport management strategy lest increasing traffic volumes swamp the beneficial effects of other measures. This would include:

- Public transport investment programs, including improved conditions for walking and cycling
- Traffic management, including rigorously enforced priorities for public transport in congested and environmentally sensitive areas
- Traffic-calming and other measures of demand management.

### *On incentive systems*

Because most critical decisions about travel behavior are made by individuals, and are largely driven by economic self-interest, tax levels and structures are often decisive in determining the amount of transport undertaken, choice of mode, technology, and fuel. This emphasizes:

- Tax reform both to restrain demand for transport to an efficient and environmentally acceptable level and to generate efficient incentives in the choice of vehicle and fuel type, size of vehicle, and location and timing of vehicle use
- Exploration of ways to overcome limitations of fiscal measures associated with multiple sectors and multiple objectives.

### *On institutions*

Because there are multiple pollutants and multiple types of ambient conditions, comprehensive, multi-instrument packages need to be tailored to specific local circumstances. This requires:

- Assessment of environmental impacts as an integral part of transport and land-use structure planning
- Development of technical competence and probity in administration as an essential prerequisite for effective action, because of the complexity of these packages

- Development of concerted action between jurisdictions and tiers of government.

The Bank can help to identify and focus on major polluters, and can help in the international exchange of experience in designing integrated urban environmental strategies. Moreover, integration of transport interventions in general municipal development packages may offer better leverage than transport-specific projects, as cities seek to reduce pollution.

## NOTES

1. IPCC 1996.
2. Lvovsky and others 2000.
3. Schipper and Marie-Lilliu 1999.
4. Eskeland and Xie 1998.
5. Eskeland and Devarajan 1996.
6. For technological detail of the issues involved, see Kojima and Lovei 2001.
7. The advisory board to the U.S. National Toxicology Program has recommended that diesel exhaust particles be listed as "reasonably anticipated to be a human carcinogen."
8. Recent studies have found a significant independent effect on premature mortality for ozone if the important nonlinear effects of temperature (and humidity) are taken into account (Holgate and others 1999).
9. Ideally, a comprehensive urban air strategy policy should involve the systematic collection of air quality data and identification of major sources contributing to the pollutants of concern. Source apportionment analysis, emissions inventORIZATION coupled with dispersion modeling, can be carried out to identify which sources should be targeted for control. These steps will then enable comparison of costs and benefits of different identified measures for improving air quality, and to identify priority actions (Kojima and Lovei 2001).
10. Lovei 1996.
11. Sulfur in diesel was lowered to 0.05 weight percent (500 parts per million by weight, wt ppm) in 1993 in the United States and in 1996 in Europe

to meet new standards for particulate emissions. This move came after a number of vehicle technology measures had substantially lowered the carbonaceous contribution to particulate emissions.

12. In the United States the Air Quality Improvement Research Program of 1989–95 found that high-emitting, poorly maintained vehicles contributed about 80 percent of total vehicle emissions but represented only about 20 percent of the population. Improving fuel quality decreased emissions somewhat but not nearly as much as changing vehicle technology (for example, by identifying and repairing old vehicles). Similarly, the European Programme on Emissions, Fuels and Engine Technologies found that the spread in emissions levels related to vehicle technologies was wider than the variations attributable to fuels.

13. In comparison with a modern, catalyzed gasoline car, a CNG-fueled car of equivalent size has been estimated to emit approximately 10 to 20 percent less CO<sub>2</sub> and particulates per vehicle kilometer, up to 25 percent less NO<sub>x</sub>, and 80 percent less CO, nonmethane hydrocarbons, and other smog-forming emissions. For buses, compared with diesel 80S Euro 2 bus, a lean-burn CNG bus has an advantage in all the major pollutants, including a 20 percent advantage in global warming gases and an 85 percent advantage in particulates, despite the fact that the modern clean diesel bus emits only one-quarter of the NO<sub>x</sub> and one-eighth the particulates of the diesel bus of 1990. The stoichiometric CNG bus has a smaller advantage over diesel in CO and CO<sub>2</sub> (only 10 percent) than the lean-burn version, but an even greater advantage in NO<sub>x</sub>. For a fuller discussion and sources of statistics quoted here, see Gwilliam 2000a.

14. For example, transportation and distribution double the wellhead price for a refueling station on the Atlantic coast of Colombia, but give a station cost five times the wellhead price for the central zone, where the distribution network is only 20 percent utilized. The real economic cost is thus lowest in urban areas close to the gas fields.

15. For example, for the barest 12-meter low-floor bus, the extra cost of a CNG vehicle might be \$30,000 on a price of \$120,000. For the more sophisticated vehicles used in urban transport in the U.S. and Western Europe, the basic cost might be twice that, while the incremental cost of CNG would not increase proportionately. That might be reduced by international unification of regulations for homologation and safety, and eventually through scale economies in OEM. In developing countries retrofitting is the norm, as the conversion of existing vehicles may be less expensive, even in the long run, than premature replacement by dedicated new vehicles.

16. LPG requires pressures ranging from 4 to 13 bar, compared with 200 bar for CNG.

17. At present the weight of available lead/acid batteries is likely to account for nearly 40 percent of the vehicle mass, limiting speed to about 40 km/h and range to about 55 kilometers. The cost of eight batteries and additional modifications required for a three-wheeler is about \$1,000, which doubles the price of electric compared with two-stroke gasoline three-wheelers. While battery technologies under development (Ni MH or Lithium Ion) may raise achievable speeds to over 50 km/h and range to over 100 kilometers, these performance levels are still much inferior to those of existing technologies.

18. ACEA (the organization of the European motor industry) and the European Commission have agreed that average CO<sub>2</sub> emissions from new cars will be reduced by one-quarter compared with current levels, to 140 grams per kilometer by 2008.

19. For further guidance on selection of technology, see TRB 1998a.

20. Nitrogen oxides (NO<sub>x</sub>) are formed during combustion as nitrogen in the air reacts with oxygen at high temperatures. The amount of NO<sub>x</sub> formed can be reduced by controlling the peak combustion temperature (for example, by recirculating exhaust gas in vehicles), by reducing the amount of oxygen available during combustion, or by converting NO<sub>x</sub> to nitrogen and oxygen-containing inorganic compounds after its for-

mation (for example, by installing three-way catalytic converters for gasoline engines).

21. Many countries have made effective use of differentiated taxation—taxing leaded gasoline more than unleaded gasoline—to encourage the use of unleaded gasoline and prevent the use of leaded gasoline in cars equipped with catalytic converters. In the absence of such a fiscal policy, control programs need to be in place to prevent permanent deactivation of catalytic converters on a large scale as a result of misfueling. The effectiveness of differentiated taxation depends on the extent to which fuel quality—in this case, leaded versus unleaded gasoline—is enforced.

22. Unfortunately, there are many examples of uncoordinated policies. In one country the government is proposing mandatory installation of catalytic converters in heavy-duty diesel vehicles without taking measures to lower the sulfur level in diesel (currently 0.7 weight percent, or 7,000 parts per million by weight [wt ppm]). At such a high sulfur level, the life of the catalyst will be shortened, and the oxidation catalyst will merely oxidize sulfur completely to SO<sub>3</sub> (and sulfate particulate matter will form), thereby significantly **increasing** particulate emissions. In another country the government mandated catalytic converters in passenger cars without specifying the emissions levels to be met—an omission that could defeat the purpose of the new requirement. In other cases, catalytic converters have been mandated without a reliable system of providing unleaded gasoline.

23. Kojima, Brandon, and Shah 2000.

24. For example, in June 2000 the current prices of three-wheelers from an ex-showroom in Delhi, inclusive of all state and local taxes, are Rs. 66,500 (US\$1,359) for a two-stroke vehicle and Rs. 70,500 (US\$1,440) for the four-stroke equivalent. In July 2001 no difference was discernible in the average price of equivalent two-stroke and four-stroke machines.

25. Typically consisting of a catalyst to oxidize HC (hydrocarbon) and CO, and secondary air to assist conversion.

26. The durability standard for catalytic converters in Taiwan, China, is still only 15,000 kilometers, although in 2000 the Society of Indian Automobile Manufactures offered to give a warranty of 30,000 kilometers for all two- and three-wheeler vehicles fitted with catalytic converters. Even this is only one year's life for a typical three-wheeler in commercial use.
27. Weaver and Chan 1996.
28. In a recent U.S. Agency for International Development (USAID)-financed program, the Society of Indian Automotive Manufactures undertook free emissions tests for 65,000 participants in 12 locations over a three-week period. Vehicles failing the test were given a free mechanical check involving carburetor adjustment, spark plug cleaning and adjustment, and air filter cleaning. As a result of this minor maintenance, emissions of HC (hydrocarbons) were reduced by 30.9 percent and those of CO by 59.7 percent.
29. Roth 1996.
30. Empirical evidence from Spain suggests that changes in the I/M program may have had considerable effects on trends in first-time vehicle registration (European Conference of Ministers of Transport 1999a).
31. European Conference of Ministers of Transport 1999a.
32. In a pilot program implemented in 1996 in British Columbia, Canada, owners were offered the choice of cash or a one-year free transit pass (worth about 1,000 Canadian dollars) on the local public transport network, to replace vehicles of model year 1983 or older. Fifty-two percent of the owners participating in the program chose the second option.
33. World Bank 1996.
34. There is a tradeoff between harmonizing fuel specifications and setting site-specific fuel standards. Ideally, provided that the distribution system can handle segregation of different fuels, cleaner (and costlier to produce) transport fuels should be used in large cities, and fuels with less-stringent specifications should only be used in areas outside urban centers. Leakages and other enforcement problems, as well as the logistics of delivering fuels of different qualities to different depots, make it difficult to implement regional differentiation cost effectively. Countries that import the bulk of their transport fuels typically find it easier to harmonize with neighboring countries than with countries that have domestic refineries. Trade considerations (between Canada and the United States, within Central America, and within the European Union [EU]) are a strong driving force for harmonizing fuel specifications. In the case of developing countries, harmonizing fuel specifications with North America or the EU is most unlikely to be cost effective.
35. The U.S. Environmental Protection Agency suggests that up to one-half of the annual U.S. traffic growth of 2.7 percent could be a result of construction of added road capacity, while a report of the British Standing Committee on Trunk Road Assessment in 1994 concluded that increasing the capacity of the road network eased congestion only temporarily because of additional generated traffic (Sactra 1994).
36. World Bank 1998.
37. Willoughby 2000b.
38. Eskeland and Devarajan 1996.